DEVELOPMENT OF A CONCEPT MATURITY ASSESSMENT FRAMEWORK

THESIS

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Abstract

Concept selection is an important investment decision point in product development. The Department of Defense too often selects concepts based on insufficient data, resulting in projects that are over-budget, over-schedule, and not what the customer wants. Decision makers must select for further development only the concepts that are effective and suitable to meet the needs of the users and require mature concepts to make an informed decision. This research proposes a stage-gated framework as a tool to assess and increase the maturity of concepts by creating an information criteria baseline at each decision gate. The framework represents a developmental scale that allows a concept to be evaluated relative to its phase of development rather than to a complete material concept. The information criteria for each gate are derived from a four-step process using well-understood systems engineering and architecture principles that, when combined at early decision points, provide the right level of information at the right time. It is anticipated that the proposed stage-gated maturity framework will provide a useful tool to practitioners and decision makers involved in the development of concepts.

Dedication

To my amazing wife.

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I would like to thank my research partner, Capt Abe Barker, for undertaking this effort with me. His hard work, dedication and good humor made this project much more enjoyable. I would, also, like to thank my research advisors, Lt Col Robb Wirthlin and Dr. David Jacques for their instruction and guidance regarding the research topic and the academic research process, they were always there to remind us that humor has no place in academic writing. Like good prison guards, they kept Abe and I in-line and helped us get out alive. For that, I am eternally grateful.

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Robinson Hughes

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LIST OF ACRONYMS

AFROC	Air Force Requirements Oversight Council
AoA	Analysis of Alternatives
AV	All View
CV	Capabilities View
CBA	Capabilities Based Analysis
CDI	Child Development Inventory
CJCS	Chairman of the Joint Chiefs of Staff
CJCSI	Chairman of the Joint Chiefs of Staff Instruction
CJCSM	Chairman of the Joint Chiefs of Staff Manual
CONOPS	Concept of Operations
DAG	Defense Acquisition Guidebook
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
DoDI	Department of Defense Instruction
GAO	Government Accounting Office
ICD	Initial Capabilities Document
JCIDS	Joint Capabilities Integration and Development System
JROC	Joint Requirements Oversight Council
LCC	Life Cycle Cost
MDA	Milestone Decision Authority
MDD	Material Development Decision
MOE	Measure of Effectiveness
MSA	Material Solution Analysis
MS A	Milestone A
NPV	Net Present Value
NRC	National Research Council
OV	Operational View
PPBE	Planning, Programming, Budgeting and Execution
ROI	Return on Investment
SAF/AQ	Assistant Secretary of the Air Force for Acquisitions
SEP	Systems Engineering Plan
StdV	Standards View
SV	Systems View
SvcV	Services View

DEVELOPMENT OF A CONCEPT MATURITY ASSESSMENT FRAMEWORK

I. Introduction

The Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3170.01G establishes the policies and the procedures for the Joint Requirements Oversight Council (JROC) to identify and assess joint military capability needs within the Joint Capabilities Integration and Development System (JCIDS). A product of the JCIDS process is a description of where the capability is deficient and includes a recommended solution to alleviate the deficiency. One purpose of the defense acquisition process is to develop and propose system concepts as possible solutions to meet the capability need. CJCSI 3170.01G discusses types of information required in a proposed concept but does not give criteria that would differentiate between a well-developed concept that is ready for consideration and one that is immature. This thesis presents a possible solution: a scale of maturity levels with corresponding criteria that the decision maker can use to evaluate concepts prior to concept selection and a developer can use to build and mature a concept.

Some Issues with DoD Product Development

Within the commercial enterprise, the result of a successful development project is a product that will earn profit for the company (Ulrich & Eppinger, Product Design and Development, 2004). The government does not earn profit from the systems it develops. According to Kaminski and Lyles (2008) the results of a successful government development project are: the system meets the needs of the users; that the developers deliver the system within a reasonable amount of time; and that the cost of development is close

to the original estimate. The Department of Defense (DoD) spends billions of dollars each year to develop these systems but, according to the Government Accountability Office (GAO), does not seem to be getting an acceptable return on investment. Many of the major systems developed by the Department of Defense require a greater amount of resources than was originally estimated to meet the user needs and systems are often delivered later than originally estimated, sometimes by years (GAO, Best Practices: Capturing design and manufacturing knowledge early imroves acquisition outcomes - GAO-02-701, 2002).

There are many suggested reasons to explain why the programs of late have not met their expected outcomes. The Government Accountability Office, the investigative organization of the U.S. Congress, cites issues that have led to the increase in cost and time of programs, which include unstable requirements, the use of immature technology, and the failure to match required resources to programs (GAO, Defense Acquisition: Employing best practices can shape better weapon systems - GAO/T-NSIAD-00-137, 2000). Other authors like Suddarth (2002) have argued the reason for relatively poor performance of recent program development is that the systems are more complex and the methods of developing systems have diminished over the years. In a study conducted in 2008 by the National Academy of Sciences, a committee chaired by Dr. Paul Kaminski and Gen (ret.) Lester Lyles (USAF) identified just about all of the suggested reasons for poor performance stated above and noted that the root of the problem is not simple. The committee noted that the causes of poor program performance and their effects are "complex and interrelated", which makes establishing causality by quantitative means nearly impossible (Kaminski & Lyles, 2008, p. 10). However, the committee did believe that

early systems engineering does contribute to successful program outcomes and found in its research that the only DoD programs that that were successful had instituted systems engineering before concept selection. The committee did qualify that early application of systems engineering is necessary for a successful development project but it is not sufficient to ensure a successful outcome. The committee did find several programs that instituted systems engineering early in the development cycle and were not successful, but every program that ignored early systems engineering failed (Kaminski & Lyles, 2008).

Within the DoD acquisition process, the development of the "alternatives for the solution" (CJCS, 2009, pp. A-5) is where the use of early systems engineering could be applied. These proposed solutions are in the form of a product or system concept. The concepts are intended to provide a solution to a deficient military capability and identify the resources required to develop the solution (DoD, DoD Instruction 5000.02, 2008). The similarities of the DoD concept to those found in the commercial equivalent will be explored in Chapter 2. However, for the purpose of this research, the working definition of a DoD concept is a solution to address an identified need and the identification of the required resources to develop that solution. The solution described by the concept can be a single product, a system or a system of systems depending upon the deficient military capability.

The Downward Spiral.

Before the Department of Defense begins a program it is required to develop estimates of when a program will be complete, what resources are required and how much it will cost to develop, deploy, and operate the system (DoD, 2008). The government cost analysts require information gathered early in the development cycle to develop

these estimates but often rely heavily on assumptions to develop the cost estimates due to a dearth of information (GAO, A Knowledge Based Funding Approach Could Improve Major Weapon System Program Ouotcomes GAO-08-619, 2008). Because these estimates have proven less than accurate the government starts development programs without correctly matching the needed resources to the development program (GAO, Best Practices: Better matching of needs and resources will lead to better weapon system outcomes - GAO-01-288, 2001). Often when a program manager should be focusing on design and development, he is unexpectedly forced to apply resources to issues like maturing technology and clarifying requirements that could have been addressed prior to the start of a program (GAO, Defense Acquisition: Employing best practices can shape better weapon systems - GAO/T-NSIAD-00-137, 2000). According to Repenning, Gonçalves, and Black (2001) the process of allocating resources to unanticipated problems, called firefighting, can become the de facto process in a development program if the earlier phases of a project are not given adequate attention. Even a temporary increase in work due to unanticipated problems that results in firefighting can permanently degrade a development team's performance. Once introduced into an organization, firefighting can become a very expensive self-reinforcing plague that can quickly spread through an entire development system. The effect of all these issues is that performance capabilities of the systems are over-promised and the cost of the system, to build and maintain, are under-estimated.

A second order effect further exacerbates the problem within government development programs. Government Accounting Office reports (GAO-01-288 (2001) and GAO/T-NSSIAD-00-137 (2000)) indicate that when the government fields development

programs and the true cost to operate a system is greater than was budgeted, the money to allow the continued operation of the fielded systems comes from programs still in development. The withdrawal of funds from the developing programs forces delays in the development, increases the cost of further development, or causes the acquisition leadership to cancel the program. Either of these actions delays the arrival of the needed capability. The final result is the user receives a system that does not perform as expected and costs more than anticipated (GAO, Defense Acquisition: Employing best practices can shape better weapon systems - GAO/T-NSIAD-00-137, 2000).

It is not difficult to connect the fiscal and temporal effects of poor program planning when one understands that decisions that determine 50-80% of a system's entire Life Cycle Cost are made before a solution is chosen at Milestone A (Kaminski & Lyles, 2008 & LT Gen Shakleford, 2009 & Blanchard & Fabrycky, 2006). The issues experienced in product development are challenging but can be addressed by the application of proper management practices early in the research and development cycle, where management has the greatest influence on a project's outcome (Wheelwright & Clark, 1992).

Genesis of a Solution.

Some management practices for the early development of complex systems are found in the discipline of systems engineering (GAO, A Knowledge Based Funding Approach Could Improve Major Weapon System Program Ouotcomes GAO-08-619, 2008). According to Blanchard and Fabrycky (2006), there is no one accepted definition of systems engineering. However, the objective of systems engineering is quite clear. It is to translate needs into a solution. The discipline of systems engineering involves an

approach that views the whole system and adopts a life-cycle orientation, which addresses all phases of a system's life, from the identification of a need to the disposal of the system. Because the discipline of systems engineering is applied at the early part of the development process, it utilizes non-quantitative analysis methods of systems architecting (Maier & Rechtin, 2002). The system wide focus and disciplined approach force a development team to ask questions very early in the development process that greatly influence a system's outcome. The work conducted early has three benefits for the developer: a reduction in the life cycle cost, reduced acquisition time, and greater visibility into the system, which should reduce the potential risks (Blanchard & Fabrycky, 2006). Blanchard and Fabrycky (2006) state that an additional benefit of the visibility that comes from applying systems engineering is an understanding of what types of resources a developer will need throughout the development process.

At present, the guiding and instructing documents for Air Force early system development indicate types of information that decision makers require but do not indicate or suggest the fidelity of the information (Assistant Secretary of the Air Force for Acquisition, 2009 and CJCS, 2007)). This lack of definition applies to all aspects of early product development, including the system concepts proposed to meet a capability shortfall. This lack of definition of what a complete concept should be adds an additional degree of difficulty to the task of choosing a concept for development. Those responsible for selecting a solution to a capability shortfall must determine the degree of fidelity and completeness of the information upon which they are about to make a decision without the benefit of a reference with which to compare. Therefore, this research seeks to develop a framework with which to evaluate the completeness of a concept.

Research Questions

This research will identify aspects of a concept that are vital to create a solid plan for a successful development program. By analyzing the best practices of commercial enterprises and applying the principles of systems architecture and systems engineering, this work will recommend levels of maturity that will give the decision maker and the developers an indication of how complete a concept is. This research will attempt to answer the following questions:

1. What is the definition of a product concept as it applies to DoD capability development?
2. What type of information does a concept require to be mature in a stage-gated process?
3. How can the definition of a mature concept account for the phases of development?
4. What is the information (criteria) required at each gate in the process?
5. What potential architecture views capture the information required by decision makers at each gate?
6. What information, if any, is important to the maturity of a concept but are not required by JCIDS or the DoDI 5000 series?

Method

First, a review of the literature addressing commercial product development, Department of Defense acquisition policy and guidance, Air Force policy and guidance on acquisition processes, and systems engineering and architecting was completed. Additionally, an search was conducted on the existing literature concerning product concepts and their maturity.

The existing literature on product development was used in conjunction with the policy and guidance of DoD acquisition to determine the relevant decision gates when a concept would be evaluated. Then, with the goal of having a complete concept at the concept selection gate, e.g. Milestone A, the type and amount of information required at each decision gate was identified. The detailed process used is described in Chapter 3.

Assumptions and Limitations

This research is based on the best practices of industry and assumes that the principles of product development found in industry can also be applied to product development within the Department of Defense. While the environment and motivations of the two communities may differ, the effects of actions conducted early in the product development process should not. The processes of each domain are designed to apply resources to the development of an idea in order to create a product that meets an identified need.

This research is not intended to recommend changes to the current Acquisition process detailed in the JCIDS and DoD policy. This research was conducted under the assumption that any outcome or recommendation would be implemented within the context of the Department of Defense acquisition process, including its development phases and decision points. However, this research will identify where and when data should be included in the concept that may differ from what is found in existing guidance.

However, the assumption that the product of this research will be used in the DoD acquisition process leads to a flawed assessment of its potential. The primary limitation of this research is that it focuses primarily on how to gauge the completeness of a concept. The purpose of the assessment, using the proposed framework, is only to address

the completeness and fidelity of the concept, not to address how well the concept meets the needs of the intended user. The assessment will identify the rigor or sufficiency of any analyses by determining if the right type and amount of information is available. Because the product development process contains a common goal and similar framework, the products of this research could be applied to a context other than the DoD. Additional research into further application of the products would be required.

Significance of Study

The literature review documented in Chapter 2 of this report shows that there is information available about product concepts and the importance of product concepts in the development process but there is little information defining what a mature or complete concept is. However, there is interest within the Air Force and other federal government agencies to develop an ability to evaluate the completeness of concepts (Vane, 2009). This research creates a framework for the development and assessment of product concepts. The framework can be used by organizations to guide the development of a product concept, and decision makers can use it to evaluate a proposed product concept. The framework should be used to mature a concept so the decision maker has sufficient information to judge the suitability and effectiveness of each concept and determine which concept (if any) should continue to the next phase of development. The information within the framework is not intended to be used as the criteria in a "check the box" event that allows a concept to proceed through a gate just because it is mature.

Overview of Remaining Chapters

The remaining chapters introduce the concepts necessary to understand this research, review the methodology used and the subsequent results, and draw conclusions and recommendations. Chapter 2 provides a review of the existing literature about product development. It will provide a comparison of the government and commercial product development processes, review the importance of beginning the process with a complete concept and reviews a working definition of DoD product concept. Methodology is discussed in Chapter 3. Chapter 4 describes the framework that was created to develop and assess a DoD product concept within the early phases of the DoD stage-gated process. Finally, Chapter 5 interprets the results of the analysis, draws conclusions, and makes recommendations for further research.

II. The Product Development Literature

This chapter will examine some of the thinking about the purpose and function of a product development process in commercial industry. It will then examine the purpose of the front-end of product development and the influence it has on the whole process.

The Development Process

Organizations whose purpose is to develop solutions, be they in the form of physical systems or processes, struggle with the challenges of designing a development process that consistently produces effective solutions to meet the needs of their customers. According to Hammer and Champy (2003), the difference between companies that win and those that lose is "that winning companies know how to do their work better" (pg 29). The companies that have designed their processes to meet the needs of their customers with profitable solutions succeed in business. Those companies that design a process, which either fails to identify the customer's need or fails to create an acceptable solution to an identified need, do not succeed.

Wheelwright and Clark (1992) contend that the goal of any development project is to "take an idea from concept to reality" by developing a product that meets the identified need and is manufacturable (pg. 111). They use the idea of a funnel to describe the process to identify and select products for development. The funnel is composed of phases separated by decision points and is designed to force a company to gather concepts, improve the concepts, select only the best ones to develop, allocate resources to the project and turn the concepts into products. At each phase of the process, enough information is collected to allow the decision makers to correctly assess a project and deter-

mine if additional resources should be allocated to its development. The process is designed to identify many potential solutions but to select for development only the ones that meet the identified need and are complete (Wheelwright & Clark, 1992).

Ulrich and Eppinger (2004) describe the generic product development process in terms of six phases: Planning, concept development, system level design, detail design, testing and refinement, and production ramp up. The generic process is intended to be tailored to the specific developmental context in order to help the organization achieve the goal of identifying customer needs and developing a marketable solution to meet those needs. Ulrich and Eppinger (2004) define a process as "a sequence of steps that transforms a set of inputs into a set of outputs" (pg 12). From their definition, each phase of the entire process can be considered a process as the output of a phase is the necessary input to the following phase. If the transition from one phase to another is used as a check-point to prevent immature projects from progressing to additional phases, the development process can help assure a quality product (Ulrich & Eppinger, Product Design and Development, 2004).

Ulrich and Eppinger (2004) further suggest that the product development process can be looked at in three ways. First, the process can be viewed as a system to develop/select a concept and transform it into a product. Second, the development process can be viewed as an information-processing system, which creates concepts, designs and specifications based upon the needs of the users, the goals of the organization and the available resources. Finally, the process can be viewed as a risk management system, which identifies and prioritizes risks early in the development process and allows the development team to eliminate key uncertainties and reduce risk.

Cooper's (1990) description of the development process is similar to those of Wheelwright & Clark (1992) and Ulrich and Eppinger (2004). His process begins with an assessment of the ideas that are intended to meet market needs and ends with the introduction of the product into the market. Cooper places great emphasis on designing a complete process and using the "gates" between stages to exercise a "go/kill/hold/recycle decision" (pg46) so that no activities critical to the success of the project are omitted. Cooper argues the gates must be used as quality control checkpoints, each with a set of criteria, and that no project be allowed to proceed to the next phase of development without meeting the criteria. The idea of using a complete process made up of phases and gates for product development is consistent with the recommendations of Wheelwright & Clark (1993), Ulrich and Eppinger (2004), and with the practice of the Department of Defense (DoD, DoD Instruction 5000.02, 2008).

Krishnan and Ulrich (2001) define product development as "the transformation of a market opportunity and set of assumptions about product technology into a product available for sale" (pg 1). The definition is a bit more general than the processes described earlier but captures the same intent of the more detailed processes. Krishnan and Ulrich (2001) looked at the decisions that are made during development and contend that how organizations develop items may differ greatly from one to another, but what is being decided is consistent at a certain level of abstraction. Each organization makes decisions by design or default on concepts, architecture, configuration, logistics, and project schedule.

Each of the processes described here are designed to help ensure a successful outcome of a development project. However, knowing what a well designed process should

contain does not ensure success. Even with the availability of a vast amount of literature on product development, creating a successful development process is challenging. Some research has shown that practice does not always follow theory (Repenning, Gonçalves, & Black, 2001). Cooper and Kleinschmidt (1986) conducted a study of 203 new product projects and found that many of the projects encountered difficulties because processes were incomplete or were executed poorly. In reviewing this data, Cooper (1990) found that there was a strong link between quality execution of the process and a successful outcome. Cooper (1990) also found that the activities that had the greatest impact on the success of a product were found in the early stages of development. The collection of activities that precede the design and production of a product are often referred to as the "fuzzy front-end." It is in this phase that the opportunities are found, ideas are created, and concepts are selected (Dahan & Hauser, 2001).

Influencing the Outcome

Within the product development literature there has been a great emphasis on understanding the factors that determine the success or failure of a development project. Several authors have attempted to synthesize the growing body of literature about success factors to gain a better understanding of product development. Brown and Eisenhardt (1995) highlighted the "the distinction of process performance and product effectiveness and the importance of agents" acting on that process (pg 343). The developing organization may have little or no control upon the influence that agents have on the development process, especially those agents outside the boundaries of the organization. However, the development process itself and the execution of the process are within the control of the development organization (Balachandra & Friar, 1997; Krishnan & Ulrich, 2001).

Cooper (1990) contends that most products fail due to "errors of omission and commission" (pg 48) in the process. Some of these errors surface in the form of not understanding user needs, defects in the product, and poor project evaluation and screening. Cooper (1990) found that the activities that precede the product development phase had the greatest impact on a projects success because they "qualify and define" (pg49) the project. The projects that executed rigorous front-end activities, or did their "homework" (pg 49), had the greatest chance for success.

Khuranan and Rosenthal (1997) argue that to execute the front-end activities correctly an organization should treat the activities of need identification, project planning and concept generation as interrelated parts of a process rather than independent activities. They separated activities within an organization's front-end process into foundational activities that span across the organization's development portfolio and project-specific activities. The purpose of the project specific activities is to "clarify the product concept, define product and [user] requirements, and develop plans, schedules, and estimates of the project's resource requirements" (pg 104). Though some research indicates that the many factors and their relative impact to the success of a project are contextual (Balachandra & Friar, 1997), the preponderance of the literature indicate the activities of understanding user needs, developing the product concept, and allocating sufficient resources have a great impact on the subsequent development phases. The focus placed on these activities is understandable since the decisions that determine 50-80% of a system's entire Life Cycle Cost (Figure 1) are made before a solution is chosen (Kaminski & Lyles, 2008 & LT Gen Shakleford, 2009 & Blanchard & Fabrycky, 2006).

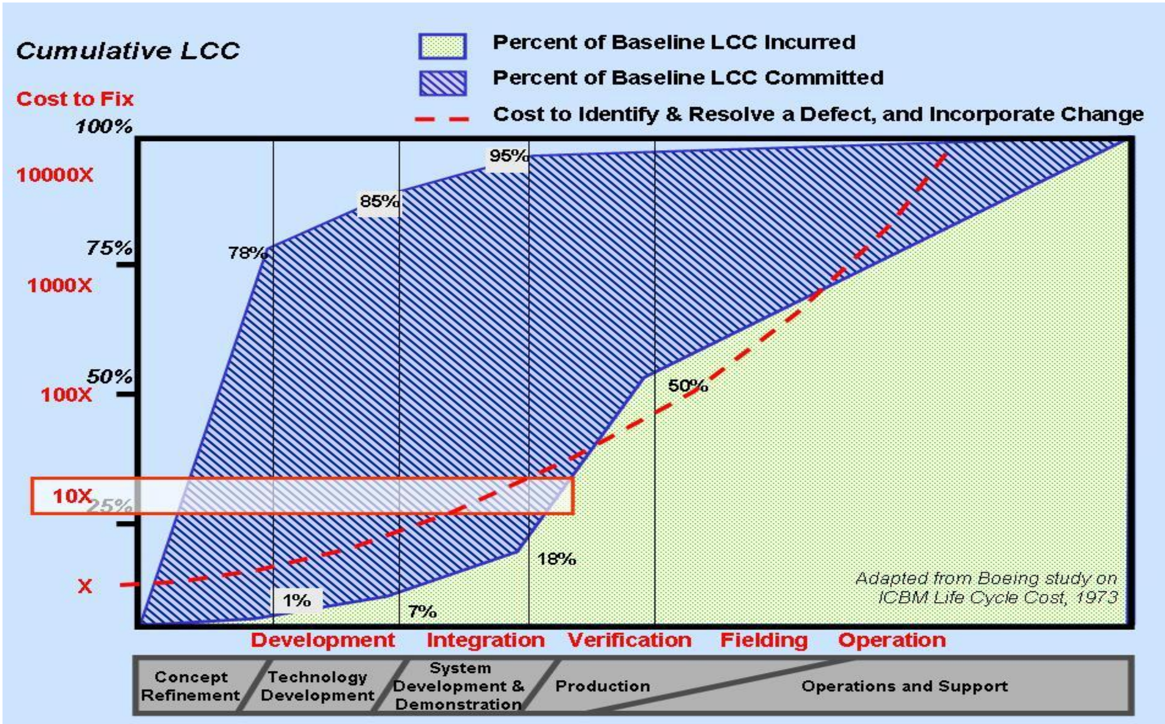


Figure 1 - "Do It Right, Do It Early; Do It Early, Do It Right", (Loren & Bullard, 2008)

Definition of a Product Concept.

To understand why a product concept, also referred to as a concept, has such influence on the outcome of a project it is necessary to understand what is in a concept. Here, like the success factors, the literature varies. While a few researchers offer an explicit definition of what a concept is, most describe the actions taken during concept development, the inputs to a concept, the outputs of a concept, and/or the purpose of a concept and of concept development. However, from these descriptions, a good understanding of what a concept "is" can be developed.

Ulrich and Eppinger (2004) define a concept as "a description of the form, function, and features of a product" (pg 15) and that it is a description of "how the product will satisfy the customer needs" (pg 98). Some of the activities that an organization ex-

ecutes to develop a concept include identifying customer needs; developing target specifications; generating, selecting and testing a concept; setting final product specifications; and planning the project, which includes determining resource requirements to develop a schedule and budget. Wheelwright and Clark (1992) describe the concept development phase as one where information is gathered on a market opportunity and ideas are developed for that opportunity. The ideas are then tested to see if they meet the needs of the market and if the development of the concept will be economically beneficial to the company. Bacon et al (1994) have a slightly different name for what Ulrich and Eppinger (2004) and Wheelwright and Clark (1992) call the concept, the product definition. The activities executed to develop the product definition are similar to those executed for concept generation: assessment of customer and user needs, identification of technical risks and opportunities, and assessment of the market environment in which the product will be offered. The outputs of the product definition process are descriptions of functions, features and price of the product; an understanding of the required technologies; and allocation of enough resources to complete development. Cooper (1993) considers the product concept as part of the product definition. His description of what information is required to be in the product definition closely matches what Ulrich and Eppinger (2004) suggest needs to be in the product concept. Burchill's (1993) process to develop a concept also begins with activities to understand the user's need and environment. Requirements and specifications are developed from the needs, solutions are created during concept development, and then a concept is selected for development. The concepts are evaluated against customer requirements and organizational constraints which implies the

resources required to develop the product are measured against what resources the organization has available.

Repenning et al (2001) state "the primary role of concept development activities is to make downstream design work more effective" (pg. 48). The way the activities of concept generation accomplish this is by understanding and documenting user needs (Repenning, Gonçalves, & Black, 2001), "explor[ing] the space of product concepts that may address the customer needs" to find the best concepts (Ulrich & Eppinger, Product Design and Development, 2004, p. 16), and integrating requirements, created from user needs, into structured design activities (Burchill, 1993). Additional objectives that should be met from the successful development of a product concept are: linking the project to the organization's goals (Wheelwright & Clark, 1992), developing product architecture (Ulrich & Eppinger, 2004 and Krishnan & Ulrich, 2001), identifying required technology and assessing the risk associated with it (Wheelwright & Clark, 1992 and Bacon, Beckman, Mowery, & Wilson, 1994), identifying project risk (Bacon, Beckman, Mowery, & Wilson, 1994), and determining the amount and type of resources necessary to complete the project (Burchill, 1993 and Bacon, Beckman, Mowery, & Wilson, 1994 and Wheelwright & Clark, 1992).

The evidence for accepting these objectives listed above can be observed by looking at what is required at the conclusion of Intel Corporation's initial two phases of product development. A cross-functional team develops the concept and product definition in the first phase and then prepares a business plan for an approval meeting. The business plan contains "a return on investment/net present value (ROI/NPV) analysis, target customers, high-level product requirements, major risks, an estimate of resources needed, a

preliminary schedule" as well as an estimate of the feasibility of the plan given its technical and timing considerations (Rafinejad, 2007, p. 163). The approval meeting is held to determine if the project should proceed to the product planning phase where architecture, design and plans are developed to "enable due diligence planning" (pg. 163) and where a detailed implementation plan is developed. At the end of this second phase sufficient architecture, design and plans have been created to describe how requirements will be realized, and a development plan has been created that contains a detailed program schedule and resource plan for the subsequent phases, a risk assessment, and identifies internal and external dependencies. Intel's management must then decide if they wish to apply resources to pursue the plan as it was proposed by the development team (Rafinejad, 2007).

While the terms and the definitions of the terms vary, the type of information that is required in the product concept is consistent. Three categories of information emerge from the literature: needs, solutions, and resources. The literature agrees that once an organization decides to pursue a development opportunity, the next action that should be taken is to identify and understand the needs of the customers and users, which includes the environment in which the product will be used. The next part of the concept generation process is to find a solution that meets the needs of the identified users. An area of concept generation where the authors do not agree is the development of product specifications. Bacon et al. (1994) and Khurana and Rosenthal (1997) suggest that technical product specifications need not be developed before a concept is selected; Ulrich and Eppinger (2004), Cooper (1993), and Bruchill (1993) argue that target specifications developed from the user needs are essential to the development, assessment and selection of a

concept. The last type of information found in the product concept is identification of the resources required to develop the concept into a product. It is essential that companies ensure they understand the cost of development and the anticipated selling price to determine if the concept is worth pursuing (Cooper R. G., 1990).

Understanding Need.

Khurana and Rosenthal (1997) suggest that once an organization identifies an opportunity the first step in the development process is a preliminary identification of customer needs and a survey of the user environment. If the organization deems the opportunity worth pursuing the next phase begins with a better understanding of user needs. Ulrich & Eppirnger (2004), Dahan & Hauser (2001), and Wheelwright and Clark (1992) suggest engaging in activities to develop a greater understanding of user needs is the initial step in the development process. Similarly, the activities to identify and define the requirements for DoD development programs are executed in a Capabilities Based Assessment (CBA) at the beginning of the JCIDS process. The purpose of the CBA is to validate any gaps in capability and to identify the mission, the operating environment, and any operational attributes and characteristics associated with the needed capabilities (CJCS, 2009). The marketing department found in a corporation is the commercial analogue to the JCIDS process. The role of marketing is to "ensur[e] that the company is delivering value" by defining who the right customers are, what those customers need, and what will meet that need and deliver value (Rafinejad, 2007, p. 60). The reason that each of these processes begin with the identification of the intended user needs is because ultimately the user acts as the final judge to determine the success of the project and the process of understanding user criteria allows an organization to propose solutions the us-

ers will find favorable (Shocker & Srinivasan, 1979). Dahan and Hauser (2001) state clearly "customers do not buy products that do not satisfy their needs" (pg 25).

Understanding user needs well in advance of any product design is integral to the larger product development process (Ulrich & Eppinger, Product Design and Development, 2004) and there are three beneficial reasons to execute a rigorous activity to accomplish the goal. First, these early activities define the project (Cooper R. G., 1990). Once the needs are captured they must be effectively communicated to the design team so that the design team can translate the customer needs into specifications for a technical solution (Ulrich & Eppinger, Product Design and Development, 2004). Second, when a project enters development with poorly defined user needs and requirements the development team is forced to clarify requirements and conduct expensive re-work to "get the project right" (Cooper R. G., 1990, p. 49 and Repenning, Gonçalves, & Black, 2001). Third, it is important to conduct a rigorous analysis of the user environment because user "insights into new product (and process and service) needs and potential solutions are constrained by their own real-world experience" and may not always be sufficient for new product development (Von Hippel, 1986, p. 791). Christensen (2003) supports this observation when stating that companies often forgo developing disruptive technologies because their customers have not yet recognized the opportunity associated with the new idea. If an organization wants to produce a novel product it must determine what is truly valuable to its customers, which cannot always be determined by asking users (Kim & Mauborogne, 2005 and Christensen, 2005).

Ulrich and Eppinger (2004) stress that the user needs are independent of any product, they are not specific to any concept, and that the best way to capture them is

through a structured process. If an organization makes the effort to understand what the user needs and the environment in which the user operates, the development team will be able to propose a solution that will likely satisfy the customer needs regardless of the technology used. This understanding of how the product will be used and what is of value to the user will also help the developer analyze the cost/benefit tradeoff associated with inevitable changes that will occur due to changing requirements (Khurana & Rosenthal, 1997). A dynamic environment is an inevitable part of new product development (Bacon, Beckman, Mowery, & Wilson, 1994) and understanding user needs will help an organization manage the change (Khurana & Rosenthal, 1997). The necessity to understand fully the user environment and the stakeholder environment is as important, if not more so, in the Department of Defense as factors that drive the design of weapon systems are often not identified in the official requirement documentation (Gillespie, 2009).

Developing the Product Concept.

Once an organization has identified an opportunity and has collected sufficient information on the customer and user needs, it must develop a solution to meet those needs. It is at this point where Wheelwright and Clark's (1992) development funnel is expanded so that many ideas (or concepts) can be identified for evaluation. These different concepts compete against one another for selection by proceeding through "screens" similar to Cooper's (1990) gates. Wheelwright and Clark (1992) suggest the initial screen not be a go/no-go decision but an evaluation of the completeness of each concept to determine which additional information is required for the eventual go/no-go decision, where one, or a few, of the best concepts will be selected for development. Ulrich and Eppinger (2004) and the Department of Defense (DoD, 2008) similarly emphasize the importance

of identifying concepts from multiple sources for evaluation. As stated earlier, Ulrich and Eppinger (2004), Cooper (1993), and Wheelwright and Clark (1992) suggest the concepts should be evaluated against target product specifications or criteria derived from the user needs. Khuranan and Rosenthal (1997) argue the product specifications should be left until after a concept is selected but any product concept should be "aligned with customer needs" (pg 106).

Cooper (1993) contends that the reason the development of a product concept is so important is that the steps leading up to and including the development of a product concept are "where the game is won or lost" (pg 121). Through their research, Wheelwright and Clark (1992) found "the outstanding organization starts development projects with concept development on a firm foundation" (pg 15). Ulrich and Eppinger (2004) found that "the degree to which a product satisfies customers and can be successfully commercialized depends to a large measure on the quality of the underlying concept" (pg. 98). Ulrich and Eppinger (2004) state that while a good concept can be poorly implemented in later development phases, a poorly created concept rarely leads to success. The successful development of the product concept should result in a solution that meets the needs of a user and leaves the developer with a reasonable idea of resources required to develop that solution. What is "reasonable" is determined by the level of project definition (AACE International, 1997; AACE International, 2005) and will be addressed in a later chapter.

Resource Allocation.

A significant insight about the dynamics of product development is "starting a project with too few resources almost always ensures it will eventually require too many"

(Black & Repenning, 2001, p. 34). Wheelwright and Clark (1992) found that companies can over commit themselves by attempting to start too many development projects and exceed their development capacity by 50-100%. When there are not enough resources to commit to the early development work, due to either over commitment of resources or poor estimation of needed resources, the activities needed to define the project can be skipped, which leads to expensive unanticipated changes later in development (Repenning, Gonçalves, & Black, 2001). It is impossible to remove all risk from product development projects since they are risky endeavors by their very nature (Hillson, Effective Opportunity Management for Projects: Exploiting Positive Risk, 2004). However, by allocating enough resources early in the development cycle to develop a product concept correctly, an organization should be able to identify risks early, make plans to address them (Bacon, Beckman, Mowery, & Wilson, 1994), and therefore have a better understanding of the cost of development (Cooper R. G., 1990).

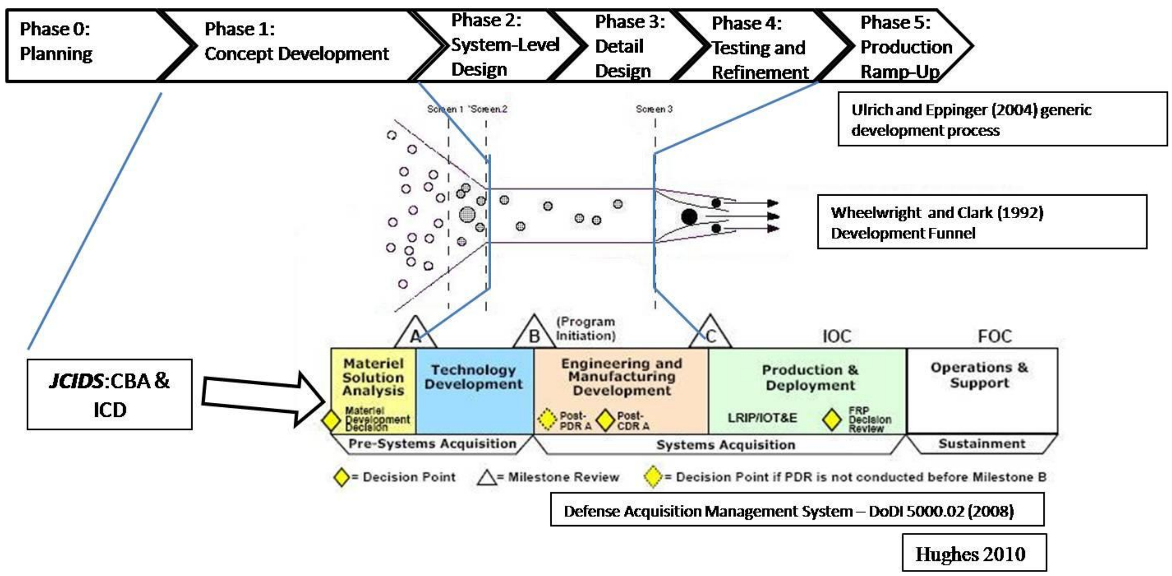


Figure 2 - Comparison of Development Processes

DoD Product Development Process

CJCSI 3170 and the DoDI 5000 series describe the requirements generation and material development processes by which the Department of Defense develops the systems it needs to meet the needs of the warfighting community. These separate processes must work in concert with a third process that provides the resources: the Planning, Programming, Budgeting and Execution (PPBE) process. The overall development process begins with the identification of user needs, continues through concept generation/selection, design, development, and deployment, and ends with disposal. The process is designed to allow potential programs to originate from multiple sources but any program must be connected to a set of user needs that have gone through the JCIDS process. Each phase of the development process is separated by a decision review that is intended to act as a "gate" described by Cooper (1990) and the development process as a whole closely mirrors the processes found in product development literature (Figure 2).

The JCIDS process performs the role of the commercial marketing function that identifies and documents the user needs and environment. The intended role of the JCIDS process is to "identif[y] and [assess] capability needs and associated performance criteria" that will be used to define the design of proposed solutions (CJCS, 2009, pp. A-2). A Capability Based Assessment (CBA) is executed to identify the mission, the operational characteristics and attributes of the desired capability, and an analysis of the risk associated with the desired capability. If a materiel solution is required, the result of the CBA will also include a recommendation for a type of solution. The authority to validate the capability shortfall found in the CBA process and to certify that a materiel solution is required to satisfy the need, falls to the Joint Requirements Oversight Council (JROC). Should the Council agree with the results of the CBA, an Initial Capabilities Document (ICD) is created from the information gathered during the CBA and it becomes the initial requirements and specifications that any proposed material solution must satisfy. The final go/no-go decision to pursue a material solution falls to the Milestone Decision Authority (MDA) at the Materiel Development Decision (MDD) review. The MDA must determine if enough information is available to begin the assessment of potential material solutions (CJCS, 2009). The order of events for the initial part of the DoD process is different than what is found in Wheelwright and Clark (1992) and Ulrich and Eppinger (2004) but the status at the end of this phase is the same in both cases. For each, a market opportunity is identified, the needs of users are identified, and the organization then decides if it is beneficial to pursue further development.

Once the decision is made to pursue a material solution Khurana and Rosenthal (1997), Wheelwright and Clark (1993), and Ulrich and Eppinger (2004) suggest a greater

understanding of user needs and environment is needed. Within the DoD process this effort should already have been accomplished by the JCIDS process (CJCS, 2009). When the MDA decides a project warrants a material solution the project enters the Material Solution Analysis (MSA) phase through the Material Development Decision (MDD) review gate (DoD, DoD Instruction 5000.02, 2008). The purpose of this phase is similar to the purpose of the second phase of Wheelwright and Clark's (1992) development funnel: to develop, assess, and select a potential material solution for a go/no-go decision. All DoD projects must pass through the MDD gate but DoD Instruction 5000.2 allows a program to proceed to any phase of development from there. A program that must continue through the MSA phase will conduct an Analysis of Alternatives to "assess the potential material solutions to satisfy the capability need documented in the approved ICD" (DoD, DoD Instruction 5000.02, 2008, p. 15) . The evaluations conducted in the AoA will look at how the potential material solutions meet the measures of effectiveness (similar to Burchill's (1993) initial product specifications), the cost and schedule to develop the potential material solution, how the solution would be used, and the overall risk associated with the potential solution (DoD, DoD Instruction 5000.02, 2008). DoD Instruction 5000.2 also mandates assessment of the critical technologies, any plans to mature and test that technology, and the manufacturing feasibility of critical technologies. The type of information reviewed during the AoA, and expected to be found in the potential material solution documentation, is of the same type found in commercial product development concepts: needs, technical solution, and resources required to develop the solution.

Proposed Definition of a DoD Product Concept

Though neither DoDI 5000.02, CJCSI 3170.01G, nor the associated manual (CJCS, Manual for the Operation of the Joint Capabilities Integration and Developement System, 2009), contain an explicit definition of the DoD equivalent to a product concept, each requires the collection of some or all of the information found in a commercial product concept. The JCIDS process is initiated by the execution of a CBA. The objective of the CBA is to understand and document user needs, conduct an analysis of which additional capabilities are needed, and determine if the capabilities can be met by a non-material solution (CJCS, CJCSI 3170.01G - Joint Capabilities Integration and Development System, 2009). The ICD adds to the information developed in the CBA by describing the operational environment in which the capability will be used and providing tasks to be accomplished with associated measurable attributes that any proposed solution must meet. The ICD should contain all the user needs against which each potential solution will be evaluated (CJCS, 2009). DoDI 5000.02 addresses the other two types of information found in product concepts: solutions and needed resources. The Analysis of Alternatives evaluates each proposed material solution based on how well it satisfies the needs documented in the ICD but also on how much the development will cost, how long the development will be, and the amount of risk that is associated with each material solution. The Material Solution Analysis phase is the first time that all three parts of a concept are present. The purpose of this phase is to give the decision makers the right type and level of fidelity of information to make the decision to invest money in the development of a solution (DoD, DoD Instruction 5000.02, 2008), which is the same purpose as product concept generation and selection (Wheelwright & Clark, 1992).

For the purpose of this research the following definition will be used to describe a DoD materiel concept: a solution that meets the needs of the customers and users, and identification of the resources required to develop the solution. The term materiel concept is used in place of product concept because the Department of Defense does not develop products but it does develop materiel solutions. This definition subsumes vague definitions of a materiel concept, "potential materiel solution" (AF Center For Systems Engineering, 2009) and some detailed ones, such as "a collection of systems and their associated organizational elements operating in accordance with a CONOPS to provide a needed capability" (Jacques, 2009). However, the proposed definition implies that all three types of information found in a product concept should be contained in a DoD materiel concept.

This term, materiel concept, and the working definition are also intentionally vague enough to be applied to every DoD development program at a certain level of abstraction. The DoD recognizes that because no two development programs are exactly alike each development program should be tailored to "fit the particular conditions of that program" (DoD, 2007). Within the DoD some capabilities may be satisfied by a system or system of systems and some may only require a single technological solution. This definition can be applied to any of these situations.

Measuring Concepts

Ulrich and Eppinger (2001) state that the process of selecting a concept is "the process of evaluating concepts with respect to customer needs and other criteria, comparing the relative strengths and weaknesses of the concepts, and selecting one or more" (pg 124). Repenning, Gonçalves, & Black (2001) suggest a project with an inadequate

concept should be canceled before the design phase and Cooper (1990) states that the benefits of well-executed front-end activities are shorter development times and improved success rates. However, there is little detailed information on how to determine if a concept is adequate or complete. Burchill (1993) developed a multi-stage process to "engineer" a product concept to help guide an organization through the difficult task but does not state how to recognize when the concept is complete. His process utilizes analytical tools to transform the information obtained from the customer into a product concept but also relies a great deal upon experience.

Perhaps the reason for such little information on how to judge completeness is that it truly may be a tacit skill acquired over time. Other reasons on why there is little information on evaluating a concept's completeness, or maturity, could be that it is extremely difficult to develop a measure for such a wide range of concepts or perhaps corporations have a method to measure concepts but consider the information proprietary. The following chapter will propose a framework by which a DoD materiel concept may be measured to determine if it is mature enough to proceed through a decision review.

III. PROCESS FOR DEVELOPING A FRAMEWORK FOR MATERIAL CONCEPT EVALUATION

A Four-Step process to develop a framework

This chapter describes the four step process that is used to develop a framework by which decision makers could evaluate the "completeness" of a material concept and by which concept developers could guide their development efforts. The four steps are:

1. Review the product development literature
2. Define a material concept
3. Determine which gates in the DoD process should be used as evaluation points
4. Identify what information is required by a decision maker at each gate

The steps are conducted sequentially, each building upon the work conducted in the previous step. However, the entire process is iterative as the information from each step is checked against what had been accomplished in previous steps to ensure that it is consistent and that the information from previous steps does not need to be updated due to new revelations. The information for the framework is selected base upon the experiences and education of the researchers and the information found in the literature. Additionally, the framework will be presented to domain experts for their review and to elicit feedback.

Review of the Product Development Literature

In addition to gaining an understanding of what research has been done on concept maturity, the purpose of this review is to define a product development concept and determine the relative influence that a concept has on the development process outcome. Within the literature, there is a general agreement of the purpose and function of a con-

cept and a definition was created for a DoD material concept, which is detailed in chapter 2. Additionally, a preponderance of the literature indicates a mature concept is necessary for a development project to be successful but it will not guarantee a successful outcome.

A vast majority of the literature is developed for, and intended to be applied to, commercial development. An analysis to compare the DoD product development process to the generic process from the literature is detailed in chapter 2 and the result is that the purpose and the function of the processes are nearly identical.

A Definition of a Material Concept

A definition of a DoD product concept needs to be created for the research. There are two reasons for developing a definition. The first reason is to develop a common language. Within the Department of Defense the term "concept" is used by many communities (including the acquisition community) and each has a unique understanding of what the term means. Additionally, the DOD has operating concepts and concepts of operations, which are not the same as product concepts. By articulating what a DoD product concept is and what information it contains, semantic arguments should be kept to a minimum. The second reason for developing a definition is that it is difficult to evaluate, or develop a framework to evaluate, something that is undefined.

The term created for the DoD product concept is "material concept" and the definition adopted for the research is: a solution that meets the needs of the customers and users, and identification of the resources required to develop the solution. This definition is intended for DoD use but it is created to incorporate the three categories of information found in a concept identified from the literature review: needs, solutions, and resources.

It is within these three categories that any information developed for the concept should be classified.

The Concept within the Stage-Gate Process

The third step in the process is to determine which decision gates will be used as events where the material concept will be evaluated. To be considered for selection, a decision gate has to conform to three criteria:

1. The gate is in the early phases of the development process where a concept has the greatest influence on the project
2. The successful transition of a concept through the gate has to result in a significant increase in resources to further develop the concept
3. There is a gate with an equivalent purpose found in the generic development process

These criteria are applied to the decision gates found in the DOD development process based upon how guidance documents describe the purpose and function of each gate. It is possible that the purpose and function of the decision gates, when policy is put into action, will differ from what is in the guidance. However, to allow for traceability of the research and for a common understanding, only the guidance documents will be used to determine the purpose of the DoD gates. After applying these criteria to the DoD product development process three gates emerged as acceptable points to evaluate the material concept. The three gates were 1) the Air Force/Joint Requirements Oversight Council (AFROC/JROC) where the user needs and capability deficiencies are validated and documented in an Initial Capabilities Document (ICD); 2) the Material Development Decision where initial solutions to meet the identified need are screened; and 3) Milestone A where a concept is selected for further development.

Determine the Information Required for a Gate

The final phase is to determine what information a decision maker requires to determine the effectiveness and suitability of the concept to meet user needs. Using the principles of systems modeling (Maier & Rechtin, 2002) and system requirement definition (Blanchard & Fabrycky, 2006), a series of questions are asked at each decision gate to scope the type of information that is being considered. The questions are:

1. What is the purpose of this gate from the perspective of the decision makers?
2. What activities occur following this gate?
3. What information will allow the decision maker to determine the effectiveness and suitability of the concept and if it is ready for the next phase of development?
4. What information is required to allow those developing the project in the following phase to be successful in their activities?
5. How might the context affect the type or amount of information needed?
6. Which Department of Defense Architecture Framework (DoDAF) views are useful to present the information?

As a final check, information identified from the series of questions had to belong to one of the three categories of information found in a concept: needs, solutions, or resources. Additionally, only information that is required to develop and mature the concept will be selected for the framework. Information already required at a decision gate by the guiding documents, which has no value to a developing concept, is excluded from the framework.

The views of the Department of Defense Architecture Framework (DoDAF) are used to present the information because the results of this research are intended to be used within the DoD acquisition process. However, a different architecture framework,

like the Zachman enterprise architecture framework (Zachman, 1987), can be used to present the information.

Using these four steps, a framework is created that gives decision makers and concept developers a “yardstick” and a common language to evaluate a concept and determine if the concept is mature enough to proceed to the next stage of development. The framework is discussed in detail in the following chapter.

IV. Framework for Evaluation

Context of the Framework

The framework developed in this chapter is intended to be used for the evaluation of material concepts within the fuzzy front-end of the product development process, which includes all the actions up to and including concept selection. Within the Department of Defense (DoD) acquisition process this would be the actions that occur up to and including the decision made at Milestone A. By this point in both DoD and non-DoD product development, when a concept is selected for development, the decisions that determine 50-80% of the life cycle cost of the product are already made (Wheelwright & Clark, 1992, Kaminski & Lyles, 2008 and LtGen Shakleford, 2009). Additionally, once a concept is selected for development an organization will then apply considerable resources to turn the concept into a product. The work conducted in this front-end of development has a great impact on the success or failure of the following development. However, as was noted in a previous chapter there is little guidance to determine if the work performed in this phase is adequate or the concept developed in this phase is complete. The framework developed in this chapter is intended to be used as a common language and yardstick to evaluate the maturity of material concepts in a stage-gated product development process. When measured against this yardstick, a decision maker should be able to determine if the concept contains the right type of information and enough of it to meet a decision gate. However, this framework is not intended to evaluate if the concept is a good solution, only that it has been well thought out.

The framework detailed in this chapter was developed with the process described in chapter 3. The decision gates were identified first. Then the information a decision

maker requires at each gate was identified. Finally, Department of Defense Architecture Framework (DoDAF) views were selected that presented the information. However, for the sake of readability, the recommended DoDAF 2.0 views are in parentheses and accompany the description of the information. Table 1 gives a description of the DoDAF 2.0 views.

Table 1 - DoDAF Views (DoD Deputy Chief Information Officer)

Description	View	Description	View
All View Operational View Systems View Services View Capability View Standards View	AV OV SV SvcV CV StdV	A mapping of system functions (activities) back to operational activities (activities)	SV-5a
Describes a Project's Visions, Goals, Objectives, Plans, Activities, Events, Conditions, Measures, Effects (Outcomes), and produced objects.	AV-1	A mapping of systems back to capabilities or operational activities.	SV-5b
The high-level graphical/textual description of the operational concept.	OV-1	The emerging technologies, software/hardware products, and skills that are expected to be available in a given set of timeframes and that will affect future system development.	SV-9
A description of the resource flows exchanged between operational activities.	OV-2	The identification of services, service items, and their interconnections	SvcV-1
The organizational context, role or other relationships among organizations	OV-4	A description of resource flows between services	SvcV-2
The capabilities and activities (operational activities) organized in a hierarchal structure.	OV-5a	The relationships among and between systems and services in a given architecture	SvcV-3a
The context of capabilities and activities (operational activities) and their relationships among activities, inputs, and outputs	OV-5b	The functions performed by services and the service data flows among service functions	SvcV-4
One of three models used to describe operational activity. It identifies business rules that constrain operations	OV-6a	A mapping of services back to operational activities	SvcV-5
The identification of systems, system items, and their interconnections	SV-1	A hierarchy of capabilities which specifies all the capabilities that are referenced throughout the architectural descriptions	CV-2
A description of resource flows between systems	SV-2	The dependencies between planned capabilities and the definition of logical groupings of capabilities	CV-4
The relationships among systems in a given Architectural Description. It can be designed to show relationships of interest, (e.g., system-type interfaces, planned vs. existing interfaces).	SV-3	A mapping between the capabilities required and the operational activities that those capabilities support	CV-6
The functions (activities) performed by systems and the system data flows among system functions (activities).	SV-4	The listing of standards that apply to solution elements	StdV-1

Assessing Maturity

If the purpose of concept development is to give a decision maker the right type and level of information to make an investment decision, then what is the right type and level? Rephrased the question becomes: when is a concept mature enough to be considered for selection? Wheelwright and Clark (1992) contend only concepts that meet user needs and are complete should be selected. However, they do not elaborate on how to identify when a concept is complete. This research indicates that elements common to any materiel concept can be evaluated with a developmental scale. These elements are pieces of information required to develop the three types of information found in a material concept as defined in Chapter 2: needs, solution, and resources. The evaluation of these elements should indicate if a concept is mature at a stage of development relative to where it should be. The proposed model herein is similar to a model used to evaluate early childhood development.

The Child Development Inventory (CDI) is a 300-item questionnaire that assesses the development, symptoms, and behavior problems of young children (Ireton, 1995). The developmental scales measure social, self-help, gross motor, fine motor, expressive language, language comprehension, letters, numbers, and general development. The measures within each of these categories for a mature 2-year-old will be different from those for a mature 4-year-old, but both children could be considered mature relative to their stage of development.

Similarly, a materiel concept that is in the initial stage of development will have less detailed information than a concept being considered for selection but both could be considered mature for their relative stages of development. The reality of any develop-

ment process is the decision maker will be the ultimate authority in determining when a concept is mature enough for selection. However, a framework that measures the maturity of elements of a materiel concept, relative to its stage of development, could be used as a benchmark for decision makers and as a guide for those who generate concepts. There are categories of maturity elements, which are found within systems engineering, which will need to be addressed in a materiel concept. Though these elements are defined as part of systems engineering, the research also indicates systems architecture elements and risk management elements require specific attention because of the information they contain that decision makers need to execute the "go/kill/hold/recycle" decision during the front-end of the stage-gated development process (Cooper R. G., 1990, p. 46).

Concept Evaluation and Selection within a Stage-Gated Process

The general purpose of every decision gate in the front end is to prevent any concept from continuing to a development phase before it is ready. At the end of a development phase, the development team needs to demonstrate to the decision maker that the concept is developed enough to proceed to the next phase and that further development of the concept will benefit the organization and the intended user. The elements used to assess and mature a concept should define the level of robust early planning required at a given decision point. A simple way to understand the appropriate time for any particular element is to relate the purpose of the element to the specific objective of the decision following a development stage. A descriptive, stage-gated process based upon processes described in the product development literature and the one used by the Department of Defense (DoD) is presented here (figure 6, pg. 55). While the forms of the processes may differ, the purpose and function of the DoD process closely mirrors that of the

process found in the literature and will be used as a baseline. Both begin with the concept development phase.

For the practitioner within the DoD and commercial development, it is important to understand the considerations and discriminators for each progressive investment decision in the concept development process. The first gate, Opportunity Identification, occurs when the Joint Requirements Oversight Council (JROC) approves and validates an Initial Capabilities Document (ICD) (CJCS, CJCSI 3170.01G - Joint Capabilities Integration and Development System, 2009), which contains originating requirements. The analysis conducted to develop an ICD should identify the shortfall in military capability, identify the user needs, and determine that a new development product is required to meet the need. The JROC must determine if this development opportunity that was identified from a market environmental analysis is adequately important for the allocation of resources.

If the JROC determines that the ICD is complete and that it identifies a valid need, the next gate, Concept Screening, occurs at the Materiel Development Decision (MDD). The primary purpose of the MDD is to act as the official entry gate to the materiel development process. It also acts as a filter to prevent the concepts that are infeasible for development, or do not meet the need identified in the ICD, from progressing any further in the development process. Any concept that the decision makers deem sufficient will undergo further maturation with deeper analysis in the Materiel Solution Analysis phase.

The third screening gate, Concept Selection, occurs at Milestone A. At this investment decision, a concept is selected based upon a set of criteria. The criteria should

include user needs, risk associated with development, cost to develop, operate and sustain the solution, and the benefits the development brings to the organization. A concept that demonstrates that it meets the criteria and is selected will, assumedly, have resources allocated to conduct preliminary design. Later gates with detailed design and fabrication/production readiness will be necessary, but substantial policy and guidance for these later gates exists for the DoD (DoD, DoD Instruction 5000.02, 2008) and will not be addressed further in this research. However, it must be understood that the information collected for these early decision gates will greatly affect and support the activities of the following development phases.

In this research, early decision gates define major milestones that are used to prevent any concept from progressing to a phase of development before it is ready. A concept can pass through a decision gate if the products for the current phase of work are complete and if the decision authority determines that there is benefit to further development. The worthiness of a concept for additional development is dependent upon contextual issues like resource constraints and political climate, in addition to a concept's maturity. A development team has no control over the contextual issues but it can ensure the proper definition and analysis associated with a decision gate has been completed. The following sections attempt to define the key criteria required to evaluate a concept's maturity at the three decision gates. In an effort to mature a concept to the point of selection, the practitioner should develop and accrue a robust set of maturity elements that, when combined, will provide sufficient information to the investment decision maker and will provide the foundation upon which the remainder of the project will be built.

Gate 1: Opportunity Identification – ICD Approval (AFROC/JROC)

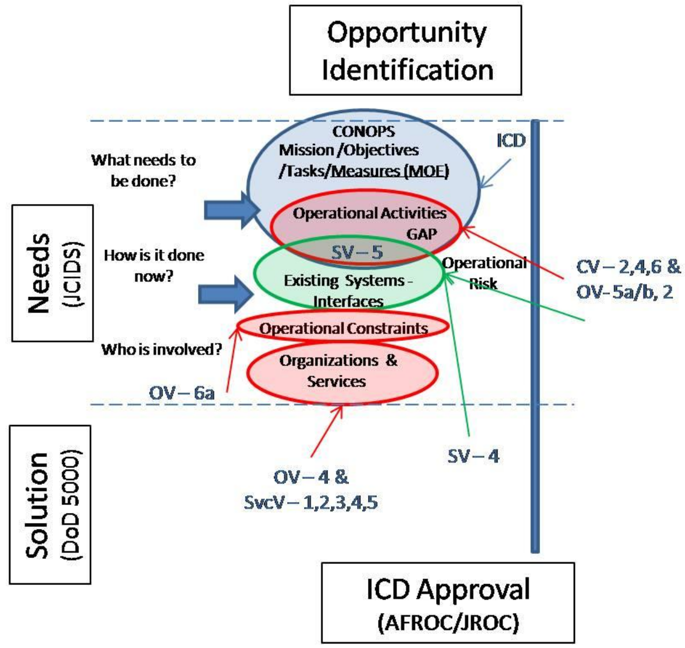
The first steps in product development are the identification of an opportunity and then an initial identification of user needs (Ulrich & Eppinger, Product Design and Development, 2004). If the organization decides the opportunity is worth pursuing, it conducts a rigorous analysis of the user needs. The order of activities in the DoD process is slightly different because the rigorous analysis of user needs is conducted before the decision to pursue an opportunity (CJCS, CJCSI 3170.01G - Joint Capabilities Integration and Development System, 2009). However, at the end of this phase an organization in either environment will have identified an opportunity, identified user needs and then must decide if it is beneficial to pursue further development.

The Joint Capability Integration and Development System (JCIDS) instruction requires analysis be conducted to identify and validate gaps in military capability, to characterize the risk associated with the gap, and determine what type of solution is required to fill the gap. Those conducting the analysis must identify how things are currently done, deficiencies in capability, what causes the deficiencies, objectives to be met, tasks to be done, and operational performance criteria associated with the tasks. The purpose of this phase is to determine key questions regarding the customer needs, such as "who needs it, why, how might they use it, what they need to do and when do they need it." If the analysis determines that a materiel solution is required to satisfy the capability deficiency, the analysis team documents the results in the ICD and then presents it to the JROC for approval. The JROC must determine if the military deficiency warrants a solution and that the solution must be a new development product.

Information Elements for Gate 1.

The ICD currently has no requirements for architecture products beyond a Concept of Operations (CONOPS) and an associated Concept Graphic (OV-1). However, there are several architecture maturity elements that should be used to support the JROC's decision at this gate (figure), and they can be developed from the documentation and information currently required in the generation of the Initial Capabilities Document. The Joint Ops Concepts and CONOPS (defined in AFPD 10-28 or IEEE Std 1362-1998) can be used to determine what the users need to do and how they expect to do it. A well defined CONOPS identifies the mission area, timeframe, assumptions with regards to projected capabilities of ourselves and our adversaries, desired effects and both the necessary and supporting capabilities that are needed. This information, as well as other information contained within a CONOPS, can be used to develop an overview of the system architecture products that will characterize the information associated with the desired capability (AV-1). The CONOPS should also include sequenced actions for the operational and support scenarios envisioned by the user. Using tools such as Use Case modeling or traditional functional decomposition, this information can be captured in operational activity models (e.g., OV-5a/b in the DoDAF (DoDAF 2.0, 2009)) which show what must be done and gives the context of how it might be done. Any known rules or constraints that may restrict operations should be captured (e.g., OV-6a in DoDAF) to give a better understanding of the user environment. In addition, the identification of any organizations involved in the activities (OV-4) and resources that flow between activities (OV-2) will help characterize the situation for the design teams in future phases. Finally, the capabilities associated with the mission (CV-2) and how those capabilities support or

interact with other operational activities (CV-6) and with each other (CV-4) should be captured.



Any existing systems and/or services (e.g U.S. Air Force) involved with the desired capability described in the ICD should be identified (SV-1, SvcV1) and their interactions should be characterized. If further definition of the interaction and various systems and services associated with the concept is warranted, resource flows and existing/planned interfaces can be identified (SV-2,3, SvcV-2,3). In order to determine gaps between needed capability (as defined by the operational activity models, e.g., OV-5) and current system capability, system and services functionality descriptions can be developed for current systems (SV-4, SvcV-4) and mapped to required operational activities using traceability matrices (SV-5, SvcV-5). If necessary during this early needs identification phase, these systems and services architecture elements would be restricted to existing systems/services (for the time frame of interest), and would contain only the detail necessary to identify the projected operational gaps and determine the reason for the gaps.

It should be noted that many of these architecture products are or may be required at later gates associated with the DoD acquisition process, but early collection of the information and definition of these products during the needs identification phase will help

in the long term effort. The initial development of these architecture elements before the first decision gate serves three purposes. First, the methodical development of the elements can be used to document existing capability, clarify any gaps in the capability, and characterize the operational risk associated with the gap. Second, the insight gained from these elements can aid in assessing the form of solution to meet the capability gap. Lastly, the elements serve as the foundation for future development phases. Each proposed solution will be designed and evaluated based upon requirements developed from the ICD.

A very important component of the ICD that is not currently being adequately addressed is that of effectiveness measures. As part of the needs identification process, needed capabilities should be identified in terms of tasks, attributes and measures. The measures at this level are best described as mission level Measures of Effectiveness (MOE's). While the JCIDS policy has always required the inclusion of MOE's in the ICD, recent reports have suggested that ICD's are not adequately addressing how the operational needs are to be quantified for subsequent evaluation of alternatives (Sadauskas, 2008). The MOE's serve a similar purpose as the initial target specifications found in the product development literature, which is to guide the development and selection of potential solutions. Identification of MOE's is critical to the concept maturation process, and is included herein as one of the maturity elements.

One final maturity element that is already required by CJCSI 3170.01G (2009) and should be developed in this early phase is an operational risk assessment. This risk assessment describes the risk of not filling the operational need. In DoD terms, this could be higher projected loss rates, greater numbers of personnel and systems allocated to mis-

sions, projected lengthening of the campaign duration, and/or increased vulnerability due to insufficient deterrent capabilities. In later stages, these operational risks will be weighed against the cost and technical risk associated with pursuing a materiel solution.

How Much is Enough?

As mentioned in a previous section of this chapter a concept should be measured relative to its phase of development. In this early phase it is difficult to state how much information is enough as the capabilities that may be brought to the JROC can range from a completely new need that has never been done to a capability with a long history that requires updating. In any case enough information must be collected and enough analysis done to show what is of value to the user, how the user currently operates, and why this way is not sufficient to do what they need. If these things can be demonstrated and documented the decision maker should have enough information to determine that the concept is mature enough for the next phase of development.

Gate 2: Concept Screening – MDD (MDA)

After an organization decides to pursue a development opportunity, they should identify as many potential solutions as possible. These ideas should be developed, combined and discarded as they pass through a series of screens so that only a few of the best ideas remain for consideration (Wheelwright & Clark, 1992). The DoD calls this screen Materiel Development Decision and uses it as a final check of the JROC recommendation to allow the further development of a materiel solution (DoD, 2008). The decision maker at MDD is called the Milestone Decision Authority (MDA). The MDA reviews the approved ICD and any proposed concepts to ensure that the material solution decision has a

solid foundation, is based on justified information, and can be developed within time and resource constraints. If the concepts are deemed adequately mature, they proceed to the next phase of development where they are further explored. In order to ensure that the approved concepts are adequately mature, and in an effort to encourage more rigor at this early gate, the MDA needs important pieces of information defined herein as key concept maturity elements.

Information Elements for Gate 2.

The information needed by MDA at Concept Screening is largely associated with development of new or modified systems included in the proposed concepts (figure 4). These concepts involve legacy systems and any anticipated changes in operations and/or materiel to existing systems should be identified. A critical piece of information for the decision maker at this stage is the scope of the required changes to implement the concept, since later decision gates will be increasingly associated with development of the individual component systems of the concept. If the full scope of the concept is not fully understood prior to a system development decision, either the full operational capability will not be realized, or significant cost impacts will be forthcoming to address needed modifications to other systems.

At this stage of concept development the actual proposed solutions are explained in terms of the required functionality (SV-4, SvcV-4), and the relationship between the need and solution is defined for the associated systems (SV-5, SvcV-5). These architecture elements may have been initially defined for existing systems during the needs identification process associated with Gate 1, but they will need to be updated and augmented for the envisioned modifications and/or developmental systems associated with a proposed concept. The interfaces and relationships between systems and services should also be updated (SV-1-3, SvcV-1-3). The technologies critical to the solution need to be identified (SV-9) and any known standards applicable to the concept (StdV-1) should be captured.

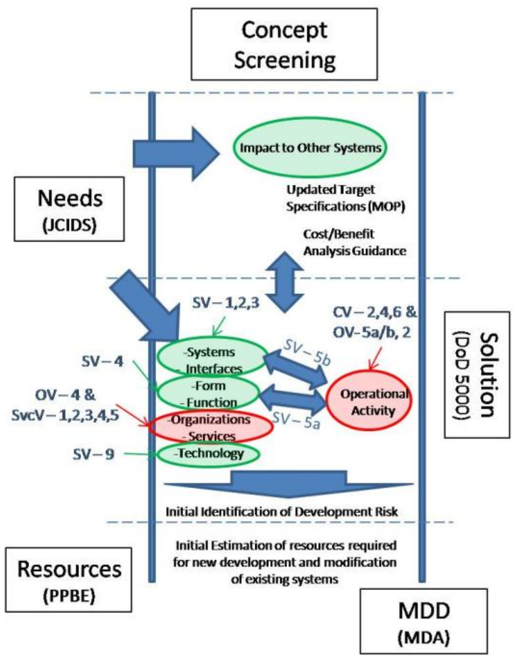


Figure 4 - Information Elements for Gate 2

The level of detail required for any architecture element at this point should be driven by the decision at hand and the decision maker. At the concept screening gate, scope and problem definition dominate the decision objectives, and the architecture definition to support this decision will likely require no more than subsystem identification for the component systems of the concept. Indeed, novel solutions considered at the concept screening gate will not likely support definition below this level. Even existing solutions where detailed information is available will not require all this detail be included in the architecture products at this early stage. The

goals of this phase are to conduct the analyses to show the proposed solution will meet the identified needs and to identify and characterize the risks associated with the solution.

Concepts that are allowed to proceed through the screening gate will need to undergo further definition and will eventually have to compete against each other. The competition is in the form of a cost/benefit analysis and the criteria against which the concepts are measured should be identified prior to the concept-screening gate. Quantitative target specifications (Measures of Performance) that describe system characteristics should be developed prior to the gate for use in the analysis. The DoD conducts an Analysis of Alternatives (AoA) during the concept refinement phase that acts as the cost/benefit analysis. The AoA study plan sets the parameters for the critical technologies and cost drivers, and decision objectives for the AoA. Sufficient risk identification associated with the technologies, interfaces, or changes to existing systems should be completed to ensure that the AoA further addresses all pertinent issues.

According to the AoA Handbook (Office of Aerospace Studies, 2008) the AoA study plan should describe how the following questions will be answered in the subsequent Materiel Solutions Analysis phase:

- What alternatives provide validated capabilities?
- Are the alternatives operationally effective and suitable?
- Can the alternatives be supported?
- What are the risks (technical, operational, programmatic) for each alternative?
- What are the life-cycle costs for each alternative?
- How do the alternatives compare to one another?

Due to the uncertainty associated with any new development, risks will still be present in a program or project regardless of the level of risk management. However, if an ample amount of rigor is applied, the more expensive risks can be identified and their

impacts minimized. Further, if risks are identified and sound risk mitigation plans are developed, a much more realistic idea of the resources required to complete development will be produced, thereby resulting in a more realistic cost estimate. It is during the risk identification phase when the important relationships between systems engineering and system architecture are defined. Risk management is the process used to manage the uncertainty associated with new development (Hillson, 2004) and therefore, risk management is a critical element of concept maturity.

Gate 3: Concept Selection - Milestone A (MDA)

The purpose of the concept selection gate is to evaluate proposed concepts with respect to customer needs and to the resources required to develop the concept (Ulrich & Eppinger, Product Design and Development, 2004). Again, this is similar to the DoD process. In 2008, the National Research Council (NRC) published a SAF/AQR commissioned study entitled "Pre-Milestone A and Early Phase System Engineering: A retrospective Review and Benefits for Future Air Force Systems Acquisition." This study examined the important elements of early systems engineering activities and their application to address the root causes of program failure during the developmental phases before the major financial investment decision is made to undergo preliminary design (NRC, 2008). This decision point is called Milestone A in the Defense Acquisition Framework. Following a successful Milestone A, a DoD development program will be initiated and one or more prime contractors will begin a preliminary design phase to demonstrate feasibility, reduce risk, and refine requirements. The program formulation elements associated with the Milestone A are defined in DoD 5000 and the DAG (DoD, DoD

Instruction 5000.02, 2008), but additional concept maturity elements will be addressed herein.

Information Elements for Gate 3.

In both industry and DoD, an investment decision must be made based upon the information and analysis contained in the materiel concept. Much of this information is efficiently and effectively conveyed and managed via architecture products. Although most architecture products are not required by DoD policy until the later Milestone B decision to enter a detailed design phase, the NRC study highlighted several important benefits to earlier development of systems architecture (NRC, 2008):

1. Architecture can mitigate internal and external system complexity risk by partitioning the system into separately definable and procurable parts.
2. Architecture can reduce lifecycle costs through the process of breaking down large systems into more easily managed components whereby potential cost and schedule risks can be identified.
3. The construction of a rigorous systems architecture developed early in the program will aid in reducing interface complexity control problems later in the program when they are much more costly to fix (NRC, 2008).

Some architecture elements created in earlier phases will need to be updated and others will require dramatic additions in the phase preceding the concept selection decision (figure 5). The specifications (MOP's) to which the solution will be measured may require updating. An initial identification of characteristics or attributes that are essential for the development of the capability should be conducted. Mitigation and management plans will need to be created for previously identified risks. A system level plan to develop new technologies or to integrate modified technologies should also be detailed for concept selection. DoD calls it a Systems Engineering Plan (SEP) and uses it to describe

the process of technology maturation (ODUSD(A&T)SSE/ED, 2008). The SEP provides traceability back to the users' needs via elements such as a CONOPs, risk identification and architecture definition eventually focusing attention towards a preferred system concept. The final version of the overall concept should be sufficient to characterize how the solution will meet the identified need, to characterize the amount of risk involved with developing the solution, and to give a reasonable idea of the full cost associated with the proposed solution. This work describes how the right combination of architecture views along with the other aforementioned maturity elements, can mature a concept relative to the early decision points in the development process.

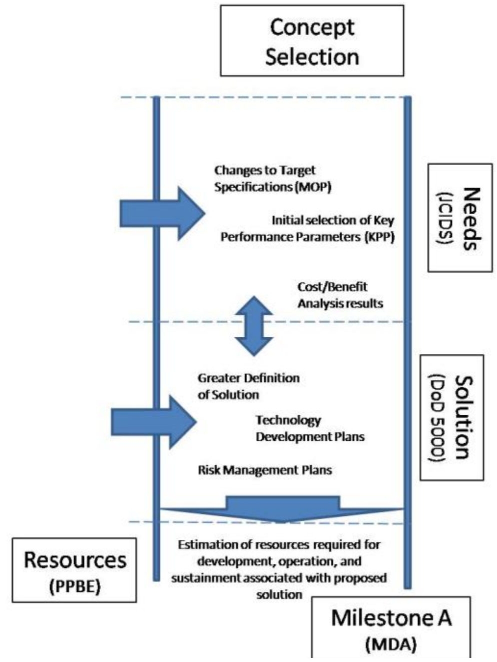


Figure 5 - Information Elements for Gate 3

An Issue of Flexibility

Every development project must pass through the Material Development Decision but from this gate, the Milestone Decision Authority can determine what phase of development the project will proceed towards (DoD, DoD Instruction 5000.02, 2008). If an MDA decides a project does not have to go through a Milestone A gate the project should still perform the activities to develop the concept associated with the pre-Milestone A phase. Similarly, any solution proposed to alleviate a deficiency that does not follow the standard development process should perform the activities to understand what is of value to the user and how the user might use the proposed solution. The reason for conduct-

ing the work of phases that a project might “skip” over is that the success of a flexible development process is “contingent upon ensuring that the objectives of every phase of the generic process are met and that critical interactions and integration issues are resolved” (Rafinejad, 2007, p. 172).

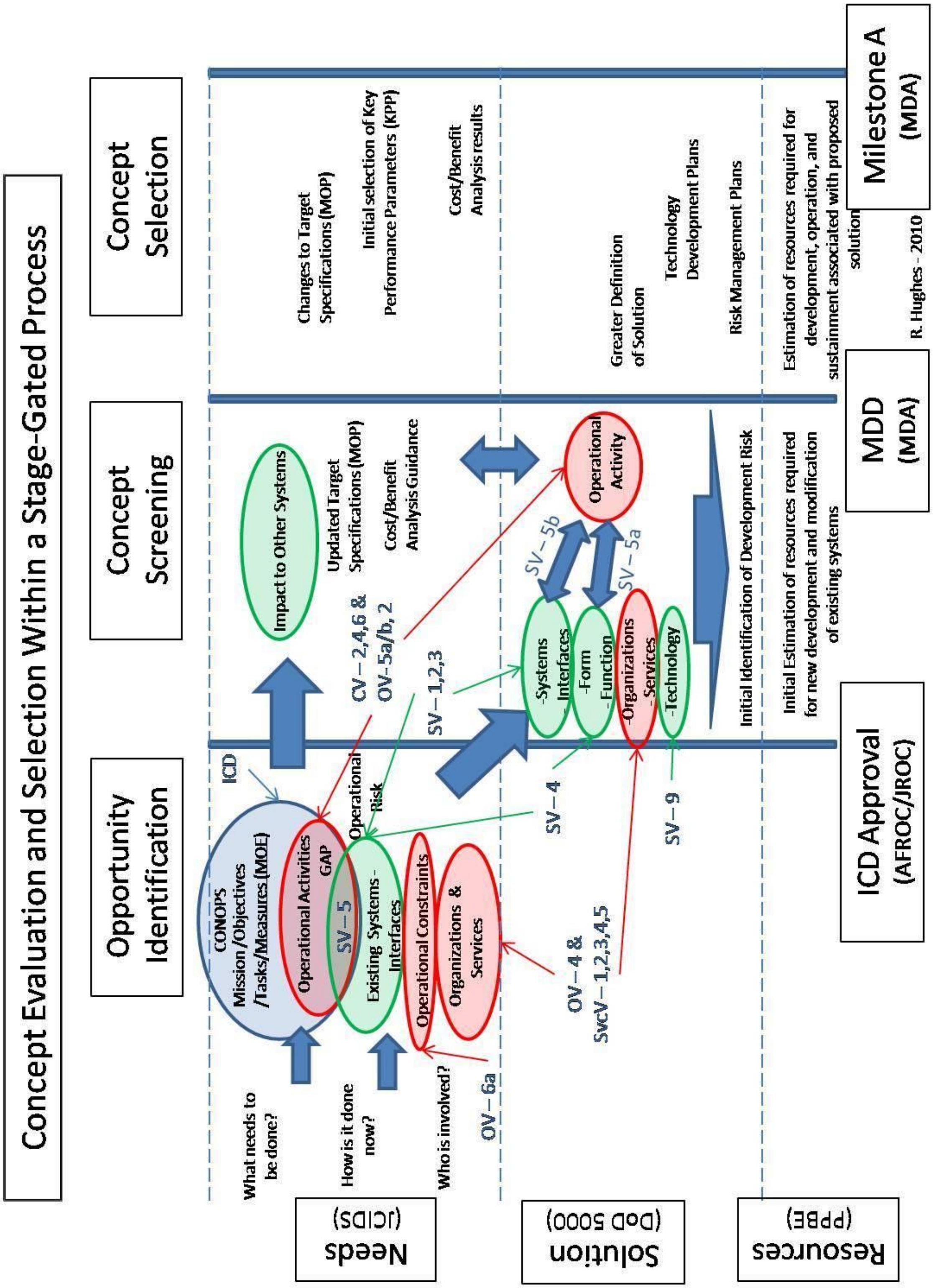


Figure 6 - Concept Maturity Framework

The Concept Development Process

The framework developed in this research is designed to act as a benchmark and common language for those evaluating and developing material concepts. The framework is designed around three major decision gates in the front end of the DoD acquisition process (figure 3). The information recommended at each gate is intended to characterize the needs of the intended users, a solution to meet those needs, or the resources required to develop the solution. The decision makers must determine if the concept before them is worthy of further development and can only make that determination if they are presented with the right type and amount of information.

The process of developing a concept is ordered and iterative. As shown in figure 3, information is developed and gathered prior to each decision gate. That information is the foundation and a guide for the development activities following the gate. This ordered activity continues through the phases preceding the three gates with the activities of each subsequent phase building upon what had been accomplished (table 2). However, this phase of product development is often very "fuzzy" so, there is an iterative aspect of the concept development process. With each new phase comes a greater amount of detail required, which could bring new revelations. Additionally, circumstances may change during the course of development that may alter or negate the work accomplished in previous phases. An evaluation should be conducted to determine the impacts of any changes due to new revelations or changing circumstances.

The concept maturity framework developed in this research was used as a benchmark similar to the Child Development Inventory (Ireton, 1995). A collaborative research project was conducted with Capt. Daniel Barker, USAF, to validate the concept

maturity framework. Two concepts, in different phases of development, were assessed and rated not based upon a fully developed concept but relative to their specific phases of development. Additionally, some informational maturity elements, of one of the concepts, were developed to further mature the concept (Barker, 2010).

Table 2 - Architecture Views by Gate

	All View	Operational Views						Systems Views						
GATES	1	1	2	4	5a	5b	6a	1	2	3	4	5a	5b	9
1	IA	IA	IA	IA	IA	IA	IA	IA	IA	IA	IA	IA	IA	
2	IT	IT	IT	IT	IT	IT	IT	IT	IT	IT	IT	IT	IT	IT
3	U	U	U	U	U	U	U	U	U	U	U	U	U	U

	Capabilities Views			Services Views					Standards View
GATES	2	4	6	1	2	3a	4a	5	1
1	IT	IT	IT	IA	IA	IA	IA	IA	
2	U	U	U	IT	IT	IT	IT	IT	IT
3	U	U	U	U	U	U	U	U	U

IA – Initial/as-is

IT – Initial/ to-be

U - Update

V. Conclusion, Discussion and Recommendations

Overview of the Research

The process of transforming an idea into a product that is of value to a customer and user is a challenging endeavor. One area of the product development process that has a great impact on the outcome of the project occurs in the initial phases: the development of the product concept. The product development literature agrees on the importance of beginning a development project with a complete product concept. However, the definition of what a complete concept is was not discussed in the literature. This research attempted to define the Department of Defense version of a product concept, a material concept, and develop a framework made up of informational elements, contained in the material concept, that could be used at specific decision gates within the DoD acquisition process. The systems architecture views, contained within the Department of Defense Architecture Framework (DoDAF), that were useful in presenting the information were then identified and incorporated into the framework. The intended purpose of this framework was to serve as a yardstick for decision makers to determine if a concept was complete enough for the next phase of development. Additionally, the framework was intended to guide those developing a material concept.

Results of the Research

The research showed that a developmental scale to measure a product concept could be created. A framework was developed to be used by decision makers to evaluate the maturity of concepts at three decision gates in the early phases of the product devel-

opment process and guide those developing the concepts prior to the decision gates. The information contained in the framework was based upon the literature and the purpose of the decision gates. DoDAF views were then selected that captured the information in a manner suitable for analysis and for presentation.

The following are responses to the research questions found in chapter 1.

Research Question 1: What is the definition of a product concept as it applies to DoD capability development?

The literature review failed to identify an accepted definition of a product concept in either the literature on commercial development or in the literature on DoD acquisition. However, the literature was quite consistent about the purpose of a product concept and what type of information should be found in a product concept. For the purpose of this research the term "material concept" was given to the DoD equivalent of a commercial product concept and was defined as a solution that meets the needs of the customers and users, and identification of the resources required to develop the solution.

Research Questions 2: What type of information does a concept require to be mature in a stage-gated process?

At the concept selection gate, a concept is required to have three types of information. First, the concept must identify the needs of an intended user and determine what is of value to the user. Second, the concept must have a solution to that need and show that the solution will meet the need. Last, the concept must characterize the risk associated with developing the solution and the resources required to develop the solution. These three types of information will be collected through the concept development process and specific "vehicles" to organize that information were identified.

Research Question 3: How can the definition of a mature concept account for the phases of development?

The type and amount of information required to determine if a material concept was mature depended upon the concept's phase of development. A type of developmental scale, similar to one used to evaluate the development of children (Ireton, 1995), can be used to determine if a concept is mature regardless of the phase of development as long as the concept is evaluated only relative to where it should be, not to where it eventually must be.

Research Question 4: What is the information (criteria) that are required at each gate in the process?

As detailed in chapter 4, and represented in graphical form in figure 3, the type of information and the amount of that information depended upon the purpose of the decision gate following the phase of development. At the first gate, the AFROC and JROC are faced with the responsibility of validating any needed capability presented within an Initial Capabilities Document (ICD) and confirming that the capability can only be realized through a new material development. The ICD, being the genesis of the material concept, must show what the users need and why they cannot accomplish what they need with existing resources. At the second gate, the Material Development Decision (MDD), the Milestone Decision Authority (MDA) determines if a project will continue into the acquisition process and screens potential solutions intended to meet the capability need identified in the ICD. In addition to the ICD, the concept must now have at least one proposed solution. The concept will have to show how the proposed solution meets the capability need, characterize the risk associated with developing the solution and give an initial estimation of the resources required to develop the solution. Between the second

gate and the last gate, Milestone A, the proposed solutions that make it through the MDD will need to be developed in greater detail. The different concepts will need to be competed against one another and development plans will need to be created for the remaining phases of the development process so, the MDA can select a concept for development.

Research Question 5: What architecture views present the information required by decision makers at each gate?

DoDAF System Arcitecture views were selected for each gate that present the necessary information. The views associated with each gate can be located in chapter 4.

Research Question 6: What information, if any, is important to the maturity of a concept but is not required by JCIDS or the DoDI 5000 series?

All the information required for a mature concept is already required to be collected by JCIDS and the DoDI 5000 series but it is required much later in the development process than it should. Many of the architecture views found in the concept maturity framework are required at gates that follow Milestone A but the research indicates that the information contained in those views are required prior to Milestone A and that those views should be created before concept selection and developed further during later phases.

Limitations of the Research

This research was conducted using the latest guidance and instructions regarding the DoD acquisition process. The purpose of each decision gate and the requirements to pass through each gate were determined by analyzing these guiding documents. However, it is possible that the purpose and function of the decision gates, when policy is put

into action, will differ from what is in the guidance. It was noted in a previous chapter that ultimately, the decision maker is the authority at a gate but this framework was created without the input of any who hold that authority.

The framework was designed around the DoD acquisition process and is intended for use by the Department of Defense. In chapter 2 the DoD process and the generic product development processes were compared and found to be nearly identical in purpose and function but additional research will probably be required before any attempt to apply the framework to another context.

This framework was developed by researchers with experience in the DoD acquisition process and have studied the product development process. The framework was presented to domain experts and their feedback was incorporated into the research. However, relative to the total number of practitioners , the number of domain experts consulted is small. Future research could be conducted to vet the framework with a larger number of domain experts.

The largest limitation of this research is that the framework is only intended to evaluate the completeness of the concept and not the sufficiency of the concept to meet the needs of the user. It is necessary for a concept to be mature to pass through a decision gate successfully but it is not sufficient. Only if a decision maker determines a concept is effective and suitable to meet the user needs will it proceed to the next phase of development.

Future Research

Through the course of this research, many issues were identified that were associated with DoD system development but were outside the scope of this research. The following are future research topics that could contribute to the body of knowledge.

First, this research was a collaborative effort with another researcher who used the framework to evaluate two concepts relative to their phase of development. In addition to assessing the concepts, efforts were made to further mature one of the concepts by developing information that was absent in the concept but recommended by the framework (Barker, 2010). The concepts were assessed relative to the criteria for the JROC and the MDD gates, but no concept was assessed relative to the Milestone A gate. Future research could use the framework to evaluate an existing material concept relative to the criteria for the Milestone A gate. This research could validate that the framework correctly assesses a material concept at each gate and that the concept could be matured further by developing the information recommended in the framework.

A second area of research could be conducted in the area of the cost estimates associated with the decision gates. A framework developed for "firms associated with the manufacturing and production of chemicals, petrochemicals, and hydrocarbon processing" to determine the type of cost estimate based upon the level of project definition was found (AACE International, 2005) in the course of this research and could be adapted to the "fuzzy front-end" of DoD capability development.

A few areas of potential research involve personnel. Currently, within the Air Force, the Major Commands are responsible for performing the analysis that supports the

development of the Initial Capabilities Document (ICD). The people performing the tasks during these early phases of the development process require the skills, education, and experience to perform marketing and systems engineering. One area of research could look at the skills, education and experience of those actually performing these tasks. Also, research could be conducted to identify how much interaction, if any, the ICD development team has with those developing the solutions. There is literature that indicates a cross functional team responsible for the entire development of the product concept is a good practice (Rafinejad, 2007).

Final Words and Takeaways

A development project started with a complete and mature product concept has the necessary foundation for a successful outcome. A complete concept identifies the resources necessary to develop the solution and characterizes the risk involved with the development. To determine the resources and understand the risk, solutions need to be developed that will meet the needs of the users. In order to propose appropriate solutions a rigorous analysis of user needs and environment is required. The activities conducted and decisions made to develop the product concept into its final form require only a fraction of the total development cost yet, can determine up to 80% of a system's life cycle cost. The stage-gated process to develop and select a product concept for development must ensure only well developed concepts that meet the needs of the users are allowed to pass through the gates. For this reason, the "go/kill/hold/recycle" decision gates require a robust set of information criteria, which each concept should meet before it is considered for further development. However, the criteria recommended for each gate in the concept

maturity framework will only benefit the development process if the "kill/hold/recycle" options are used for concepts that do not meet the necessary criteria.

A final takeaway of this research is that a complete, well-developed concept is necessary but it is not sufficient to guarantee success. The development process is complex and requires great execution as well as great planning. The intent of the concept maturity framework is to address only one of the many issues experienced in DoD concept development.

BIBLIOGRAPHY

1. DoD Deputy Chief Information Officer. (n.d.). *DoDAF Architecture Framework 2.0*. Retrieved 02 01, 2010, from http://cio-nii.defense.gov/sites/dodaf20/index.html
2. AACE International. (2005, February 2). Recommended Practice No. 18R-97: Cost Estimate Classification System - As Applied In Engineering, Procurement, , and Construction For The Process Industries. *AACE International Recommended Practices* .
3. AF Center For Systems Engineering. (2009, August 06). Concept Maturity Workshop Outbrief. Dayton, Ohio, USA.
4. Bacon, G., Beckman, S., Mowery, D., & Wilson, E. (1994). Managing Product Definition in High-Technology Industries: A Pilot Study. *California Management Review* , 32-56.
5. Balachandra, R., & Friar, J. H. (1997). Factors for Success in R&D Projects and New Product Innovaiton: A Contextual Framework. *IEEE Transactions on Engineering Management , 44* (3), 276-287.
6. Barker, D. A. (2010). *Validation of a Concept Maturity Evaluation Framework.* Air Force Institute of Technology, Systems and Engineering Management. Wright Patterson Air Force Base: Air Force Institute of Technology.
7. Black, L. J., & Repenning, N. P. (2001). Why firefighting is neve enough: preserving high-quality product development. *System Dynamics review , 17* (1), 33-62.
8. Blanchard, B. S., & Fabrycky, W. J. (2006). *Systems Engineering and Analysis* (4th ed.). Upper Saddle River, New Jersey, USA: Pearson Prentice Hall.
9. Buede, D. M. (2000). *The Engineering Design of Systems.* New York, New York, USA: John Wiley & Sons, Inc.
10. Burchill, G. (1993). Concept Engineering: A Complete Product-Concept Decision-Support Process. *Design Management Journal* (Fall), 78-85.
11. CJCS. (2009, March 01). CJCSI 3170.01G - Joint Capabilities Integration and Development System.
12. CJCS. (2009, February). *Manual for the Operation of the Joint Capabilities Integration and Developement System.* Retrieved February 4, 2010, from Acquisition Community Connection: https://acc.dau.mil/CommunityBrowser.aspx?id=267116&lang=en-US
13. Cooper, R. G. (1990, May-June). Stage-Gate Systems: A new tool for managing Products. *Business Horizons* , pp. 44-54.

14. Cooper, R. G. (1993). *Winning at New Products: Accelerating the Process from Idea to Launch* (second ed.). Reading, Massachusetts: Addison-Wesley.

15. Dahan, E., & Hauser, J. R. (2001). *Product Development - Managing a Dispersed Process.* Cambridge, Mass: MIT Center for Innovation in Product Development.

16. DoD. (2007, November 20). DoD Instruction 5000.01.

17. DoD. (2008, December 08). DoD Instruction 5000.02.

18. DoDAF 2.0. (2009). *DoD Architectural Framework V2.0.*

19. GAO. (2008). *A Knowledge Based Funding Approach Could Improve Major Weapon System Program Ouotcomes GAO-08-619.* Washington D.C.: United States Government Accountability Office.

20. GAO. (2001). *Best Practices: Better matching of needs and resources will lead to better weapon system outcomes - GAO-01-288.* Washington D.C.: United States Government Accountability Office.

21. GAO. (2002). *Best Practices: Capturing design and manufacturing knowledge early imroves acquisition outcomes - GAO-02-701.* Washington D.C.: United States Government Accounting Office.

22. GAO. (2000). *Defense Acquisition: Employing best practices can shape better weapon systems - GAO/T-NSIAD-00-137.* Washington D.C.: United States Government Accountability Office.

23. Gillespie, D. M. (2009). Mission Emphasis and the Determination of Needs for New Weapon Systems, a PhD thesis for MIT.

24. Hammer, M., & Champy, J. (2003). *Reengineering the Corporation.* New York: Collins Business Essentials.

25. Hillson, D. (2004). *Effective Opportunity Management for Projects.* New York: Marcel Dekker, Inc.

26. Hillson, D. (2004). *Effective Opportunity Management for Projects: Exploiting Positive Risk.* New York, New York, United states: Marcel Dekker.

27. Ireton, H. (1995). Assessing children's development using parents' reports: The Child Development Inventory. *Clinical Pediatrics , 34* (5), 248.

28. Jacques, D. D. (2009, August 13). (C. D. Barker, & C. R. Hughes, Interviewers)

29. Kaminski, P. G., & Lyles, L. L. (2008). *Pre-Milestone A and Early-Phase Systems Engineering: A Retrospecitve Review and Benfits for Future Air Force Acquisition.* National Academy of Sciences, Air Force Studies Board. Washington D.C.: The National Academies Press.

30. Khurana, A., & Rosenthal, S. R. (1997, Winter). Integrating the Fuzzy Front End of New Product Development. *Sloan Management Review* , 103-120.

31. Loren, J., & Bullard, R. (2008). Do It Right, Do It Early;Do It Early, Do It Right: Reshaping the DoD SE Investment Paradigm. *INCOSE.* Amsterdam.

32. LtGen Shakleford, M. (2009, August). Concept Maturity: Key to Improving Air Force Acquisition. Fairborne, Ohio, USA.

33. Maier, M. W., & Rechtin, E. (2002). *Teh Art of Systems Architecting* (2nd ed.). Boca Raton, Florida, USA: CRC Press.

34. NRC, N. R. (2008). *Pre-Milestone A and Early-Phase Systems Engineering: A Retrospective Review and Benefits for Future Air Force Acquisition.* National Acadamies Press.

35. ODUSD(A&T)SSE/ED. (2008). *Systems Engineering Plan Preparation Guide, Version 2.01.* Washington, DC: ODUSD(A&T)SSE/ED: Office of the Deputy Under Secretary of Defense for Acquisition and Technology, Systems and Software Engineering, Enterprise Development.

36. Office of Aerospace Studies. (2008). *Analysis of Alternatives (AoA) Handbook.* Kirtland AFB, NM: Air Force Materiel Command (AFMC) OAS/A9.

37. Rafinejad, D. (2007). *Innovation, Product Development and Commercialization.* Fort Lauderdale, Florida: J. Ross Publishing.

38. Repenning, N. P., Gonçalves, P., & Black, L. J. (2001). Past the Tipping Point: The Persistence of Firefighting in Product Development. *California Management Review , 43* (4), 44-63.

    i. Sadauskas, L. (2008). Implications of Capability-based Planning on Requirements Engineering. *NDIA SE Conference.*

    ii. Shocker, A., & Srinivasan, V. (1979). Multiattribute Approaches for Product Concept Evaluation and Generation: A Critical Review. *Journal of Marketing Research* , 159-180.

39. Ulrich, K., & Eppinger, S. (2004). *Product Design and Development.* Boston: McGraw-Hill.

40. Ulrich, K., & Eppinger, S. (2004). *Product Design and Development* (4th ed.). Boston: McGraw-Hill.

41. USD/DAU. (2009). *Interim Defese Acquisition Guidebook.*

42. Vane, G. (2009, July 6). *JPL Concept Maturity Level Nimenclature.* Retrieved August 15, 2009, from Space Policy Online: http://www.spacepolicyonline.com/pages/images/stories/JPL_re_Concept_Maturity_Level_Nomenclature.pdf

43. Von Hippel, E. (1986). Lead Users: A source of Novel Product Concepts. *Management Science , 32* (7), 791-805.

44. Wheelwright, S. C., & Clark, K. B. (1992). *Revolutionizing Product Development.* New York: The Free Press.

45. Zachman, J. (1987). A framework for Information Systems Architecture. *IBM Systems Journal , 26* (3), 454-470.

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14. ABSTRACT Concept selection is an important investment decision point in product development. The Department of Defense too often selects concepts based on insufficient data, resulting in projects that are over-budget, over-schedule, and not what the customer wants. Decision makers must select for further development only the concepts that are effective and suitable to meet the needs of the users and require mature concepts to make an informed decision. This research proposes a stage-gated framework as a tool to assess and increase the maturity of concepts by creating an information criteria baseline at each decision gate. The framework represents a developmental scale that allows a concept to be evaluated relative to its phase of development rather than to a complete material concept. The information criteria for each gate are derived from a four-step process using well-understood systems engineering and architecture principles that, when combined at early decision points, provide the right level of information at the right time. It is anticipated that the proposed stage-gated maturity framework will provide a useful tool to practitioners and decision makers involved in the development of concepts.

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